

Clumpy Disc and Bulge Formation

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ABSTRACT

We present a set of hydrodynamical/Nbody controlled simulations of isolated gas rich galaxies that self-consistently include SN feedback and a detailed chemical evolution model, both tested in cosmological simulations. The initial conditions are motivated by the observed star forming galaxies at $z \sim 2-3$. We find that the presence of a multiphase interstellar media in our models promotes the growth of disc instability favouring the formation of clumps which in general, are not easily disrupted on timescales compared to the migration time. We show that stellar clumps migrate towards the central region and contribute to form a classical-like bulge with a Sersic index, $n > 2$. Our physically-motivated Supernova feedback has a mild influence on clump survival and evolution, partially limiting the mass growth of clumps as the energy released per Supernova event is increased, with the consequent flattening of the bulge profile. This regulation does not prevent the building of a classical-like bulge even for the most energetic feedback tested. Our Supernova feedback model is able to establish a self-regulated star formation, producing mass-loaded outflows and stellar age spreads comparable to observations. We find that the bulge formation by clumps may coexist with other channels of bulge assembly such as bar and mergers. Our results suggest that galactic bulges could be interpreted as composite systems with structural components and stellar populations storing archaeological information of the dynamical history of their galaxy.

Key words: galaxies: formation, galaxies: evolution, galaxies: bulges, galaxies: interactions.

1 INTRODUCTION

The formation of bulges is still a matter of large debate. Observations suggest that the Sersic index (n) of a large sample of bulges are smaller than what previously thought, specifically for late type galaxies, suggesting that secular processes play an important role in formation of this component. These observations establish a clear dichotomy in bulge properties, classifying them into *classical*- ($n > 2$) and *pseudo*- ($n < 2$) *bulges* (Fisher & Drory 2008). Mergers are considered as one possible mechanism of formation as well as secular evolution. Both formation modes seem to generate bulges with different properties in numerical simulations, being the first ones more prompted to yield de Vaucouleurs (high- n) density profiles compared to the second ones which would favour more exponential ones (low- n). However, there is currently not theory to explain the Sersic index values in bulges. Recently, a third possibility has come out from new

observations of high redshift galaxies and high resolution, improved numerical models.

The high-redshift observations show that the most intense star formers in the Universe are galaxy discs at $z \sim 2$. Their morphologies are consistent with thick, gas-rich discs, rotationally supported with circular velocities of ~ 200 km/s. A peculiar feature of these galaxies is that their discs show the presence of several giant clumps of $\sim 10^8 - 10^{10} M_\odot$ (e.g. Förster Schreiber et al. 2011) where an intense star formation is observed (e.g. Förster Schreiber et al. 2009). Gravitational instabilities in gas-rich turbulent discs have been proposed as the fundamental mechanism to account for this fragmentation. This scenario is also able to explain the bulge formation via clump migration (Elmegreen et al. 2008; Genzel et al. 2008; Bournaud et al. 2011; Guo et al. 2011).

Cosmological simulations (Ceverino et al. 2010), ana-

lytical works (Dekel et al. 2009) and simulated idealized discs in isolation (Immeli et al. 2004; Bournaud et al. 2007, 2011) have succeeded to explain most of the observed clump properties. However, a remaining aspect should be addressed, that is, the ability of clumps to survive the effect of SN feedback. Several works have disregarded clump disruption by SN thermal heating, claiming radiation pressure to play a more dominant role (Dekel et al. 2009; Murray et al. 2010). Hydrodynamical simulations including radiation pressure models have found that clumps disrupt before coalescing the bulge (Hopkins et al. 2011; Genel et al. 2012). However, Krumholz & Dekel (2010) use analytical models to conclude that radiation pressure would not be efficient to disrupt clumps in high redshift galaxies. The strongest evidences suggesting that clumps survive long enough to reach the bulge are the observational estimations of clump ages (Genzel et al. 2011), and the radial gradients detected in the clump properties (Guo et al. 2011).

In this paper, we revise the clump survival problem within the context of our adopted SN feedback and multiphase model, and analyse the impact that clumps might have on bulge formation. For this purpose, we use hydrodynamical simulations of isolated gas-rich discs and a realistic physically-motivated SN feedback model implemented with a multiphase treatment of the ISM (Scannapieco et al. 2005, 2006). We also explore how different mechanisms of bulge formation (clumps migration, mergers, bars) compete with each other, and trace their structural and stellar population properties. These last results could help to unravel the dynamical galactic history contained in the archaeological information of bulges.

2 NUMERICAL SIMULATIONS AND CLUMP IDENTIFICATION

We analysed a set of simulations run by using an extended version of the GADGET-2 code which includes a realistic SN feedback model, implemented with a multiphase treatment of the ISM (Scannapieco et al. 2005, 2006). This code allows the coexistence of gas clouds with different thermodynamical properties and is able to describe the injection of energy into the ISM producing the self-regulation of the SF and the triggering of mass-loaded galactic outflows, without the need to introduce mass-dependent parameters, or to change discontinuously particle momentum to start a wind or temporary suppression of the radiative cooling. The radiative cooling rates are estimated according to the metallicity of the gas.

We studied a set of hydrodynamical simulations of pre-prepared disc galaxies initially composed of a dark matter halo (following a NFW profile), a Hernquist bulge and an exponential disc, with a total baryonic mass of $M_b \sim 5 \times 10^{10} M_\odot$. All experiments were run with a 50 percent of discs in form of gas in order to reproduce observations of $z \sim 2$ gas-rich galaxies (Daddi et al. 2010). We use 200 000 dark matter particles, 100 000 stars initially distributed in the stellar disc and bulge, and 100 000 initial gas particles in the disc component with a mass resolution of $\approx 2 \times 10^5 M_\odot$. A gravitational softening of $\epsilon_G = 0.16$ kpc was adopted for the gas particles, $\epsilon_S = 0.20$ kpc for the stars, and $\epsilon_{DM} = 0.32$ kpc for the dark matter. The initial metallicity of the gas

has been set so that the simulated discs lie on the mass-metallicity relation at $z \sim 2$ as explained in Perez et al. (2011).

We analysed five simulations of the isolated gas-rich disc varying the ISM and the SN feedback models. Three simulations, S.FeMu, S.ModFeMu and S.StrFeMu, have the same multiphase ISM model but explore different SN feedback efficiencies, parametrized by their energy release, E_{SN} . The other two simulations, S.Mu and S.BasicSPH, do not include SN feedback. The former includes the multiphase ISM model of Scannapieco et al. (2005) but without SN feedback, and the latter has star formation but with no SN feedback nor multiphase ISM. We also study the clump growth during galaxy interaction and bar formation using two simulations: S.FeMu_Int and S.FeMu_Bar, respectively. We note that the interacting case and its associated isolated simulation (S.FeMu_Int and S.FeMu) were previously used by Perez et al. (2011) to investigate the evolution of metallicity gradients in high- z galaxies¹. S.FeMu_Bar is a version of S.FeMu with a shorter radial scale length in order to have a centrally dominating disc prone to bar instability. The main parameters of the analysed simulations are summarized in Table 1 for the initial conditions and the after ≈ 3.5 Gyr of evolution.

Consistently with previous works, our simulated discs fragment into large clumps. In order to identify them, we use a morphological criteria similar to that used by Bournaud et al. (2007), based on the fact that clumps represent local over-densities. First, we compute the face-on projected surface density on a polar grid, defined to control the particle noise. Then, we keep the pixels which represent over-densities compared to the average density at the same radius. This over-density criteria is controlled by a free parameter, set to eliminate extended connected regions as spiral arms. Selected clumps have masses ranging from $\approx 10^7 M_\odot$ to $\approx 10^9 M_\odot$ with a mean at $\sim 10^8 M_\odot$ (see Fig. 2), which are in agreement with previous observational and numerical works.

3 CLUMPS SURVIVAL

Our simulated gas-rich discs fragment into large clumps, where an intense star formation activity is detected. In good agreement with observations (Guo et al. 2011), we find that the individual contribution of clumps to the global SFR of the host galaxy is in general lower than 10%, with a collective contribution of $\approx 45\%$ on average, and a maximum of $\sim 60\%$. Even with an active star formation in clumps, the rate at which they form stars is less than one percent of the clumps mass per free-fall time, which determines a dimensionless star-formation rate efficiency, e_{ff} , to be lower than 0.01 (see eq. 6 of Krumholz & Dekel 2010).

In Fig. 1 we show the the projected baryonic mass distributions for S.FeMu at two different times (after 0.25 and 0.60 Gyr of evolution, upper and lower panels). We also displayed colour contours defined according to star particle ages. It is clear from this figure that the youngest stellar population are located mainly in clumps. We can also see a

¹ This simulation was referred as SimVI by Perez et al. (2011).

Table 1. Main parameters of the numerical experiments. E_{SN} is amount of SN energy release by each event in units of 10^{51} erg s $^{-1}$. $n_{initial}$ and n_{final} are the initial and final Sersic indexes of the bulges, and $Re_{initial}$ and Re_{final} the respective effective radius. (B/T) is the final bulge-to-total stellar masses, where the bulge is computed within $2Re$. Errors correspond to one standard deviation.

Simulations	E_{SN}	$n_{initial}$	n_{final}	$Re_{initial}$	Re_{final}	B/T
S.BasicSPH	—	1.4 ± 0.2	1.6 ± 0.2	0.63 ± 0.01	0.67 ± 0.02	0.24
S.Mu	—	1.3 ± 0.2	3.5 ± 0.1	0.61 ± 0.02	0.33 ± 0.01	0.32
S.FeMu	0.5	1.4 ± 0.1	4.2 ± 0.1	0.65 ± 0.02	0.33 ± 0.02	0.31
S.ModFeMu	0.7	1.3 ± 0.2	3.2 ± 0.1	0.61 ± 0.02	0.40 ± 0.02	0.34
S.StrFeMu	1.0	1.3 ± 0.2	2.9 ± 0.1	0.61 ± 0.02	0.58 ± 0.01	0.29
S.FeMu–Int	0.5	1.3 ± 0.1	2.9 ± 0.3	0.53 ± 0.02	0.51 ± 0.02	0.39
S.FeMu–Bar	0.5	1.6 ± 0.2	2.3 ± 0.2	0.47 ± 0.02	0.30 ± 0.02	0.35

stellar age gradient which is consistent with a migration scenario (Guo et al. 2011). Effectively, by inspecting the time evolution of the galaxy, we find that clumps migrate to the central region of the galaxy on timescales that, on average, are about 0.5 Gyrs, in agreement with previous analytical and observational results (Dekel et al. 2009; Guo et al. 2011; Genzel et al. 2011).

In order to study the origin and survival of clumps in our simulations, we explore the ability of different ISM and SN feedback models to form and preserve clump structures in disc simulations. We find that in the basic SPH model, the formation of clumps is prevented because gravitationally instability on the gaseous discs is more difficult to developed due to the over-smoothing of the density and temperature distributions. Conversely, in all our simulations with a multiphase ISM model, gravitational disc instabilities (Toomre 1964) are promoted as a consequence of a better description of density and temperature gradients (Scannapieco et al. 2006). The growth of this instability drives the fragmentation of discs in clumps which locally match $Q_{Toomre} < 1$.

We compare the density and temperature distributions of gas particles in our basic SPH simulation (S.BasicSPH) with those in the multiphase model (S.Mu). The multiphase ISM produces a more ‘clumpy’ and concentrated gas distribution with at least three order of magnitude larger densities than the basic SPH. As expected, these larger over-densities are found to match the clump distribution and are formed by cold gas ($\simeq 10^4$ K). Within these clumpy gas concentrations, densities are so large that their cooling times are significantly shorter compared to their dynamical time. Consequently, gaseous clumps in our multiphase ISM model are transformed in bound stellar systems which, capable to survive the disc shearing, migrate and coalesce to the galactic centre. The inclusion of SN feedback regulates their stellar masses by heating the gas and triggering outflows as shown below. Hence, our main analysis will be focused on simulations with the multiphase ISM model (S.Mu, S.FeMu, S.ModFeMu, S.StrFeMu), unless specifically stated.

Fig. 2 shows the clump mass distributions for experiments with the multiphase ISM model and different SN feedback energy parameters: without SN feedback (magenta), with our mild SN feedback model ($E_{SN} = 0.5e51$), with a moderate ($E_{SN} = 0.7e51$) and a strong ($E_{SN} = 1e51$) SN feedback at a reference time as an example. We find that clumps can survive SN winds even in the simulation with strong SN feedback. However, their growths are lim-

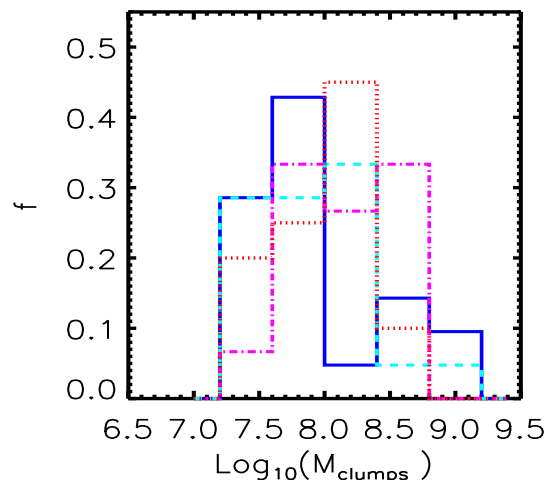


Figure 2. Histograms of stellar masses for clumps in S.FeMu (blue, solid line), S.Mu (magenta, dotted-dashed line), S.ModFeMu (cyan, dashed line) and S.StrFeMu (red, dotted line).

ited by the SN energy release: the highest mass clumps are found in the simulation without SN feedback and in the mild SN feedback run. The increase of the SN energy event produces the decrease in the average clump mass as expected as the gas is heated up and partially blown away. Note also that clumps are continuously accreting new material along their evolutionary path; they are not close systems but they highly interact with their surrounding ISM. Stronger SN outflows also contribute to the formation of less gravitational bounded clumps which can be more easily disrupted. We find that the mean bound energy for the strong SN feedback run is ~ 58 per cent of that corresponding to our mild SN feedback model. It is important to note that the SN feedback models used in this work are capable to reproduce the observed galactic mass-loading factors (Scannapieco et al. 2006) as well as those of individual clumps such that the mass-loss rates typically exceed the star formation rates by a factor of a few (Genzel et al. 2011). For clumps in the strong SN feedback model, we report the highest extreme mass-loading factors of ~ 7 , which nevertheless are within observed values (Genzel et al. 2011).

Clumps in our simulations are not fully disrupted by

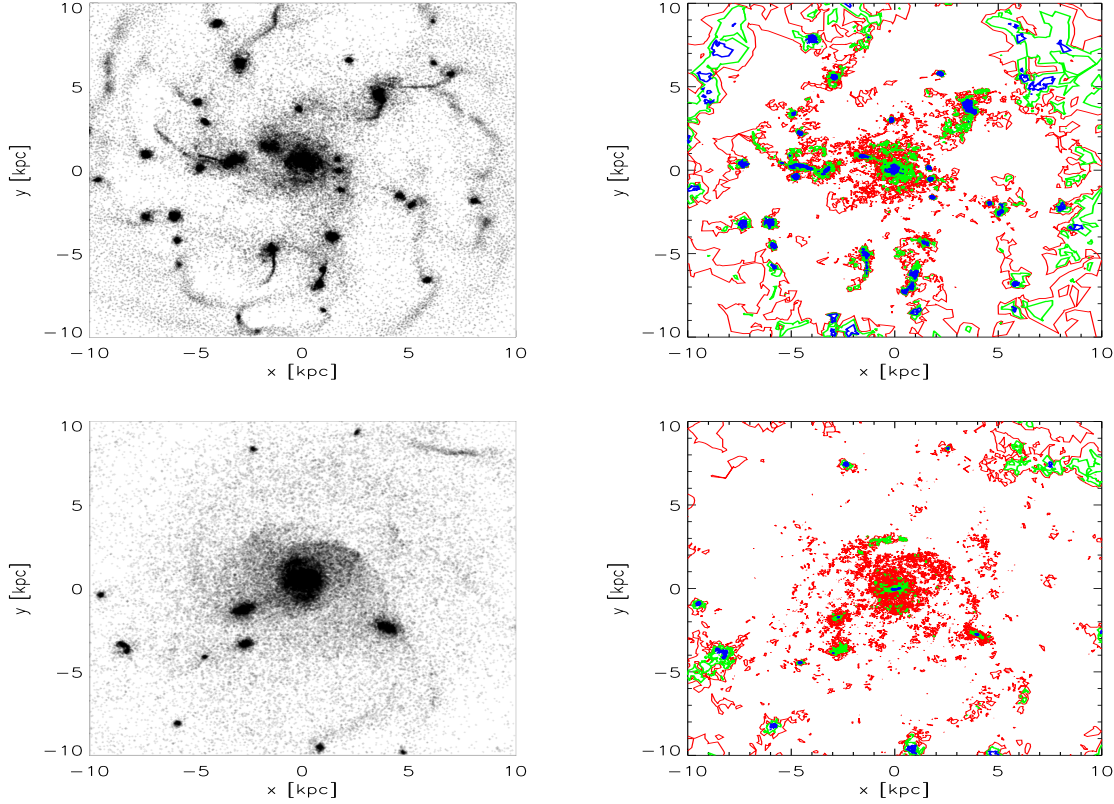


Figure 1. Projected baryonic mass distributions (left-handed panels) and colour contours of stellar ages (right-handed panels) for the simulated galaxy disc in S.FeMu experiment at an early and advanced stages of evolution (lower and upper panels). Old, intermediate and young populations are indicated by red, green and blue lines, respectively.

the action of SN feedback as reported by other authors. This discrepancy could stem from differences in the numerical codes, which might lie on the details in the ISM and feedback models. Firstly, we note that our code does not include other sorts of feedback apart from thermal heating from SNe. Radiation pressure has been claimed to be the dominant mechanism over other sources of feedback, including the SN thermal heating (Dekel et al. 2009; Murray et al. 2010). Numerical results from Hopkins et al. (2011) and Genel et al. (2012) support this claim. However, its role in disrupting clumps remains debated (Krumholz & Dekel 2010; Krumholz & Thompson 2012). Since we have not a physically-motivated radiative pressure so far implemented in our code, we follow Bournaud et al. (2011), and explore a stronger SN feedback model (S.StrFeMu) as a way to somehow mimic an extra energy contribution for other possible sources, finding no significant variations in our conclusions.

The SN feedback model developed by Scannapieco et al. (2005, 2006) is one of the most physically-motivated currently available. In this model, the SN energy is fractionally distributed into the gaseous neighbours of two different ISM phases, denoted as *hot* and *cold*. The energy injected into the hot phase is instantaneously thermalised and, that received by the cold phase is stored in a *reservoir*, defined for each gas particle in this phase. This energy is accumulated until it is enough to modify the thermodynamical properties of these particles so they match the corresponding ones of the hot phase. When this

happens, the cold particle is promoted to the hot phase dumping its reservoir energy into its internal energy. This scheme prevents artificial losses of SN energy by the cold phase and ensures the triggering of mass-loaded galactic winds which are capable to reproduce the observations (Genzel et al. 2011).

Beyond differences in the feedback schemes, our simulations distinguish themselves by the adopted multiphase scheme (Scannapieco et al. 2006) as discussed before. In S.Mu experiments which includes the multiphase ISM but not the SN feedback, clumps consume their gas into stars, persisting (~ 0.5 Gyr) as a bound stellar system until coalesce in the galactic center. The inclusion of SN feedback in our models (S.FeMu, S.ModFeMu and S.StrFeMu) partially limits their mass growth and weakly reduces their lifetimes, even though is able to reproduce the observed mass-loading factor of clumps. The survival of clumps for these experiments could be explained because the SN feedback in our model self-regulates the conversion of gas into stars in such a way that the dimensionless star-formation rate efficiency, e_{ff} , is found to be within the survival regime (Krumholz & Dekel 2010). In brief, all our simulations with multiphase ISM model promotes disc instabilities driving the formation of clumps which migrate and shape a classical bulge.

3.1 The structure of the bulges

In order to quantify the role of SN feedback in the bulge formation via clumps, we analyse the final structure of bulges for S.BasicSPH, S.Mu, S.FeMu, S.ModFeMu and S.StrFeMu discs, by computing their stellar density profiles and performing a disc-bulge decomposition by using an exponential profile for the disc and a Sersic law for the bulge. The decomposition was carried out in radial range internally limited by the gravitational softening and extended up to 8 kpc. Note that we use the relation: $bn = 2 \times n + 0.32$ (Mac Arthur et al 2003) reducing the degree of Sersic parameter space in order to make the fitting process more efficient.

Fig. 3 shows these stellar density profiles plotted as a function $r^{1/4}$ with the aim at emphasizing deviations from classical bulges, principally in the central regions (Fisher & Drory 2008). According to this figure and the derived Sersic indexes (Table 1), we find that pseudo-bulges ($n < 2$) are only formed when using the basic SPH technique (with no multiphase ISM or SN feedback model). Classical-bulges ($n > 2$) are always formed when our multiphase ISM model is switched on. We analysed the gas and temperature distributions of the run without and with the multiphase ISM model, finding that this is capable of reproducing much better density and temperature gradients allowing the co-existence of clouds with different entropies, generating a turbulence medium which better represents the underlying physics (Scannapieco et al. 2006).

When the SN feedback model is switched on the growth of the clumps are regulated by the SN energy released by event as already shown in Fig. 2. As a consequence, when the SN energy increased, the bulge profiles get flatter, but even in the strong SN feedback run the resulting bulge has $n > 2$. We also find that the ratio B/T decreases significantly in the case of the strong SN feedback model as the outflows are more violent and can remove gas or even prevent new gas infall more easily. These results suggest that our SN feedback model can regulate the growth of clumps but it does not preclude the building of a classical bulge if sensitive SN energy values are adopted. Hence, classical bulges could emerge in a secular scenario by clump migration and not only from mergers.

4 MULTI-CHANNEL BULGE FORMATION

As mentioned in the previous section, clump migration should be considered as an alternative channel of bulge formation. In order to disentangle its contribution, we investigate how clumps are able to modify the final density profiles of our S.FeMu disc. Fig. 4 shows how the different stellar components contribute to the final density profile of the galaxy. Note that the stellar population initially distributed in the bulge component will be hereinafter refereed as old bulge, and, analogously, for the old disc. These old stars can be followed along the galaxy evolution and thus, separated from the younger stellar population formed out from the gaseous disc and located in the emerging new bulge and disc components.

Fig. 4a shows that the new stellar populations (solid blue line) significantly contribute to the final density profile in the central region, but also indicates that the new

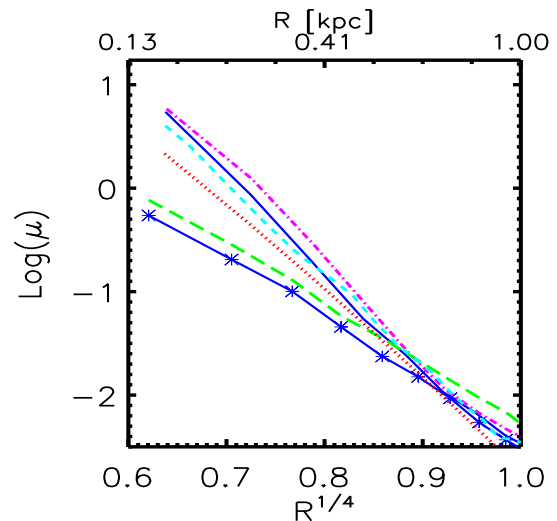


Figure 3. Stellar surface density profiles in the central region of simulated galaxies in S.BasicSPH (green, long dashed line), S.FeMu (blue, solid line), S.Mu (magenta, dotted-dashed line), S.ModFeMu (cyan, dashed line) and S.StrFeMu (red, dotted line). The initial stellar density profile is plotted for comparison (asterisks and blue solid line). See Table 1 for initial and final Sersic indexes.

stars formed in clumps (blue asterisk) are those which have the major role in shaping the bulge. Note, however, that we specifically excludes the new stars formed in any clump eventually developed in situ in the bulge, i.e. we only consider the new stars formed in clumps identified on the disc²

In agreement with previous works (e.g., Elmegreen et al. 2008; Ceverino et al. 2010), our results indicate that a secular process of bulge formation, i.e. the clump migration, allows the formation of a classical-like bulge with a Sersic index of $n \sim 3 - 4$ (see Table 1). Note that this result seems to be in tension those of Bournaud et al. (2011), where a central bulge but with less steeper profile, $n \sim 1.7$, is reported. This discrepancy likely emerges from the fact that their kinetic feedback might be more efficient destroying clumps which, on the other hand, is consistent with the relatively young stellar population of clumps found in the latest phases of their merging experiments. Also note, that they find the Sersic index by fitting the profile from 1.6 kpc ($0.3 * R_{1/2}$), much further out than our fitting range.

We also study the relative contribution of the new stars and a preexisting bulge and a disk component to the final bulge structure, including the time evolution of the different stellar density profiles in S.FeMu (Fig. 4b). The result indicates that stars distributed initially in the Old Bulge gradually become less dominant, while new stars (formed primarily in clumps) have a more prominent role. This suggests a dynamical interaction between both stellar populations, which is sculptured in their final relative mass distribution.

² Note that we use a morphological bulge-disc decomposition, defining the radius of bulge as twice the effective radius as obtained from the Sersic-exponential fitting of profiles. (blue asterisk).

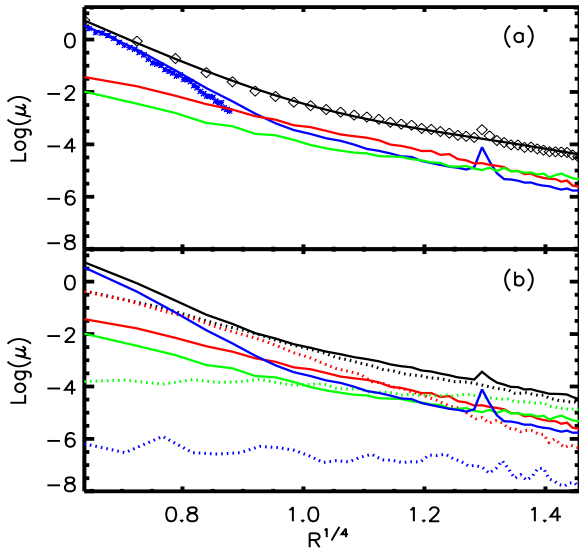


Figure 4. (a) Final density profiles of the simulated disc for the S.FeMu experiment. Total stellar component (i.e., old bulge, old disc and new stellar population) produces a profile shown by black diamonds, fitted by a $n \sim 4$ Sersic-Exponential function (solid black line). Contributions from old bulge, old disc and from the new stellar population were discriminated (red, green and blue lines, respectively). Blue asterisks show new stars identified at the final stage within the bulge but formed in any of the clumps along the galaxy evolution. (b) Time evolution of density profiles for each stellar components in S.FeMu: Total stellar components (black), old disc (green), old bulge (red) and new stars (blue). Solid (dotted) lines show the final (initial) profiles. Thus, dotted blue line represents the new stars formed during the initial snapshot.

Besides clump migration, other processes as bars and mergers are well known to shape the bulge mass distribution. Several numerical works have contributed to show that mergers are able to form classical bulges ($n \sim 3$) and bars induce pseudo-bulge ($n \leq 2$) formation. However, the presence of clumps in these processes have been little explored. Particularly, our motivation, as a first approach to the subject, is to contribute to answer the question: if clump migration by itself develops classical bulges, does the combination with other mechanisms make even more difficult to explain bulge formation in a Λ Cold Dark Matter cosmology?, i.e. it will produce an even large excess of classical bulges in spiral galaxies at low redshift (see Bournaud et al. 2011).

In order to explore this topic, we investigate how these mechanisms might compete with each other or reinforce the action of clumps by studying their contributions to the density profiles. In Fig. 5, we show final profiles of the isolated disc of S.FeMu, of its associated model with bars (S.FeMu_Bar) and of the merger remnant in S.FeMu_Int. The bulge growth can be followed by comparing final density profiles (solid lines) with their respective initial ones (dash-dotted lines), or more quantitative, by their Sersic indexes (see Table 1).

Our results indicate that clump migration in isolated discs can be as effective as mergers in developing a classical-bulge (high Sersic index), but with a less extended bulge

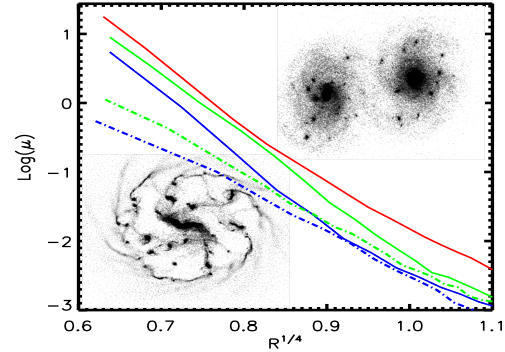


Figure 5. Final stellar density profiles (solid lines): S.FeMu (isolated disc, blue), S.FeMu_Int (merger remnant, red) and S.FeMu_Bar (bar, green). Initial profiles are shown for reference (dash-dotted lines). Note that for construction, the initial profile of the merger remnant coincides with that of the isolated disc. It is remarkable that models with similar Sersic index value like S.FeMu and S.FeMu_Int ($n \sim 3 - 4$) came out of very different dynamical histories.

growth than mergers, i.e. lower effective radius and bulge-to-total stellar masses (see Table 1).

Our model with a more dominant disk (S.FeMu_Bar) presents a different evolution compared with the S.FeMu. As all the simulated cases, the gas rich-disc fragments generating clumps, but the model also develops relatively soon a large scale bar-like structure, similar to that observed in some barred galaxies with a clumpy stellar distribution (Hernández-Toledo et al. 2011). The gas distribution and motion is affected by this bar triggering an inflow, which in turn weakens the large scale bar. This behaviour is not unusual in gaseous bar simulations (Norman et al. 1996; Immeli et al. 2004).

It is well known that bar robustness is highly sensitive to the numerical time step (Shen & Sellwood 2004; Klypin et al. 2009). In order to check the robustness of this trend, we re-run the model S.FeMu_Bar with a smaller time step. In both of our experiments a large scale bar forms and weakens. The overall result of our barred experiments is that bar formation produce a less compact pseudo-bulge with index $n \sim 2.3$, even when clumps form. Our result, could be explained as the dominant effect of the large scale bar which induces a mass redistribution over the contribution of clump migration. The pictures emerging out of our analysis may provide an explanation to the study recently reported by Okamoto (2012), where bar formation and clumpy star formation co-exist in a simulated galaxies within a cosmological context, with a final bulge with a low Sersic index and a dominant mass contribution from a central starburst (also see, Shigeki & Takayuki 2011). It is important to say that a systematic scan of the parameter space is required in order to accurately characterize this evolution channel.

5 CONCLUSIONS

We used hydrodynamical simulations of isolated gas-rich discs crafted to mimic star forming galaxies at $z \sim 2-3$.

The simulations include a realistic SN feedback model implemented with a multiphase treatment of the ISM (Scannapieco et al. 2005, 2006), which has been proven to be able to describe galactic global properties comparable to observations (Scannapieco et al. 2008, 2009; De Rossi et al. 2011).

We find that the presence of the inhomogeneous, turbulent multiphase medium in our simulations promotes the formation and growth of gravitational disc instability favouring stellar clumps formation. For our specific multiphase ISM and SN feedback model, the gas in clumps is transformed into stars at a rate of a less than one per cent of the clump mass per free-fall time, producing bound systems within the survival regime (Krumholz & Dekel 2010), and stellar age spread of the order of 500 Myr. This indicates that the survival of clumps is not strongly affected by our SN feedback model, if sensitive values are adopted for the SN energy released. Our SN feedback model is also able to reproduce the observed mass-loading factors of clumps (Genzel et al. 2011).

The picture which emerges out from the analysis of our numerical experiments is that bulge formation by clumps may co-exist with other channels of bulge assembly producing realistic values of Sersic index and bulge-to-total mass ratios. As a consequence, clump coalescence becomes a viable channel for bulge formation. In this scenario, bulges could be interpreted as compound systems similar to those observed in the Milky Way (Babusiaux et al. 2010) and some external galaxies (Fisher & Drory 2008), with different relative contributions of pre-existing bulge, old disc and new stars, which may store archaeological information of the galaxy assembling.

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